An X-ray examination apparatus and a method of controlling an output of an X-ray source of
an X-ray examination apparatus

The invention relates to an X-ray examination apparatus comprising:
- a controllable X-ray source arranged to generate an X-ray beam;
- an X-ray detector arranged to produce a first image upon an interception of the X-ray
  beam;
- image processing means arranged to process at least a part of the first image with a
  grey-level compression function in order to compress the first image into a second
  image.
        The invention further relates to a method of controlling an output of an X-ray
source of an X-ray examination apparatus by means of a dose control signal, said method
comprising the steps of:
- acquiring a first X-ray image;
- processing at least a part of the first X-ray image with a grey-level compression
  function in order to compress the first X-ray image into a second X-ray image.
        An embodiment of an X-ray examination apparatus as is set forth in the
opening paragraph is known from US 5, 388, 138. The known X-ray examination apparatus
comprises an X-ray source arranged to emit an X-ray beam, an X-ray detector arranged to
convert X-rays radiated from the X-ray source into an X-ray image, an X-ray controller
arranged to control a dose of the X-ray source upon a receipt of a dose control signal. In the
known X-ray examination apparatus first the X-ray image is compressed by means of a
suitable grey-level compression function which has a point of inflection beyond which a
gradient thereof is reduced. A resulting image has a compressed range of grey-levels with
respect to the original image. By this an influence of overexposed areas on the overall image
is reduced. The dose control signal in the known X-ray apparatus is formed by luminous
energy control means on basis of pixel values obtained in a determined region of interest of
the compressed image in such a way that an average brightness of the region of interest is
kept substantially at a pre-determined level.
        It is a disadvantage of the known X-ray examination apparatus that in order to
determine the dose control signal a delineation of the region of interest is required. A
procedure of a delineation of the region of interest requires an attention of a skilled person

2

and, therefore takes additional time. Next to this, for medical cases where the region of interest must be altered for purposes of detailed medical analysis, the known approach may be inappropriate, as due to a possible inclusion of a new neighboring region with a substantially different grey-level the resulting average image brightness may be substantially

5   different with respect to an initial value, thus requiring a substantially different dose control signal. During a step of an image post-processing it is not possible to influence the dose control signal.

It is an object of the invention to provide an X-ray examination apparatus wherein a universal dose control signal for the X-ray source is determined without a

10   delineation of the region of interest.

To this end the X-ray examination apparatus according to the invention comprises control means arranged to compute an average grey level value of pixels of the second image and to provide a dose control signal to the X-ray source in order to control the X-ray beam, the dose control signal being determined from a comparison between the

15   computed average grey level value and a pre-stored reference value.

The technical measure of the invention is based on the insight that for cases when a measuring field exceeds the region of interest a problem arises that highlighted parts in the measuring field at the end lower the grey level of the region of interest. On the contrary, the dark parts in the measuring field make the region of interest appear brighter then

20   required. These phenomena are intrinsic to the operation of the dose control system which determines a value of the dose control signal based on a comparison between a computed average pixel grey level value of the image and a reference value. In case the image comprises highlighted pixels, the average grey level value will increase, and a corresponding dose control signal will cause a corresponding reduction of an intensity of the X-ray source.

25   As a result, the grey-level of intermediately lighted pixels corresponding to the region of interest will be reduced. A presence of low-lighted pixels in the image will have an opposite effect on a resulting grey level of intermediately lighted pixels. Therefore, the image processing means and the control means of the X-ray apparatus according to the invention are arranged to substantially reduce an influence of the high- or low-lighted pixels on the

30   resulting computed average pixel grey level value by applying a suitable grey-level compression function. In order to reduce an influence of solely the high- or lowlighted pixels on the majority of the pixel grey-levels the grey-level compression function preferably comprises a suitable number of ranges, for example two, with a different grey level conversion factor. After the influence of these pixels on the resulting image grey-level is

3

reduced, a universal dose control signal is determined by comparing the computed average
grey level of the resulting second image to a pre-stored reference value. Preferably, the pre-
stored reference value corresponds to a required grey-level of the image. In the X-ray
apparatus according to the invention the dose control signal is determined in a full-automated
5   way thus requiring no interference with a skilled medical person for a subjective delineation
of the region of interest. Moreover, as the influence of the high- and/or low-lighted pixels on
the overall image is substantially eliminated, the resulting dose control signal is valid for
adequate viewing and examining of regions which belong to all possible regions of interest.
              In an embodiment of the X-ray examination apparatus according to the
10   invention the grey-level compression function comprises a monotonous function with a first
linear range, a second linear range and a third linear range, the second linear range
comprising the pre-stored reference value, a grey level compression factor of the second
linear interval having substantially a value of one, grey level compression factors of the first
linear range and the third linear range being substantially lower than one.
15   It is found to be particularly advantageous to provide the grey-level
compression function as a tri-linear curve, wherein a mid-segment is selected in such a way
that the intermediate grey levels of the first image are accepted unchanged. In this way
picture elements with diagnostic information are uncompressed. The corresponding grey
level compression factors for the outer segments are substantially depressed thus maximally
20   reducing an influence of the low- and high-lighted pixels on the average pixel value of the
resulting image. As a result the second image comprises a weighted contribution of
highlighted, low-lighted and intermediately lighted pixels. It must be noted that in order to
insure a stable behavior of the control means the grey-level compression function must be
monotone and continuous. The respective grey level compression factors must all be positive.
25   In a further embodiment of the X-ray examination apparatus according to the
invention said apparatus further comprises computing means arranged to construct a grey-
level histogram of the first image and to determine corresponding boundaries of the first
linear range, the second linear range and the third linear range from said grey-level
histogram.
30   It is found to be advantageous to individualize the partition of the grey-level
compression function by constructing a grey-level histogram for each new set-up of an X-ray
acquisition. In this way a shutter setting can be taken into account more precise and
individually for each illumination session. Preferably, for images taken with a different

4

angulation with respect to an object under examination, the grey-level histogram is
constructed for each acquired image.

In a still further embodiment of the X-ray examination apparatus the
computing means is further arranged to calculate a loop gain correction factor and to apply
5   the loop gain correction factor to the dose control signal.

According to this technical measure a time behavior of the control loop is
restored. Due to the fact that after image processing by means of the grey-level compression
function the resulting pixel values of the image have lost their diagnostic value, the first
images of next acquisitions should be starting-point for diagnostic interpretation. It is found
10   to be advantageous to restore the loop gain value by first determining the loop gain correction
factor and secondly by applying the loop gain correction factor to the dose control signal.
Due to the chosen linearity of the grey-level compression function the loop gain correction
factor can be easily determined. A corresponding mathematics will be given with reference to
Figure 1.

15   The method of controlling an output of an X-ray source of an X-ray
examination apparatus according to the invention comprises the following steps:
     -    computing an average grey level value of pixels of the second X-ray image;
     -    comparing the computed average value and a pre-stored reference value;
     -    providing a dose control signal to the X-ray source, said dose control signal being
20   determined from said comparison.

According to the method according to the invention the influence of the low-
and high-lighted pixels on the overall average pixel value of the image is substantially
reduced thus providing a universal dose control signal enabling a correct viewing of all image
areas.

25

These and other aspects of the invention will be further discussed with
reference to figures.

Figure 1 presents a schematic view of an embodiment of an X-ray examination
30   apparatus according to the invention.

Figure 2a presents a schematic view of a first embodiment of resulting
computed average by means of application of a tri-linear grey-level compression function.

Figure 2b presents a schematic view of a second embodiment of resulting
computed average by means of application of a tri-linear grey-level compression function.

5

Figure 3 presents a schematic view of an embodiment of a grey-level
histogram of an acquired X-ray image.

Figure 4 presents a schematic view of an embodiment of an implementation of
the method according to the invention.

5

Figure 1 presents a schematic view of an embodiment of an X-ray examination
apparatus according to the invention. The X-ray examination apparatus 1 comprises the X-
ray unit 2 arranged to communicate data to the control and processing means 10. The X-ray
10   unit 2 is arranged to generate a beam of X-rays 1f propagating from an X-ray source 1c. In
order to obtain diagnostic data a patient (not shown) is placed in an acquisition volume V,
located between the X-ray source 1c and an X-ray detector 1d, where a transmission X-ray
image is formed. Embodiments of a suitable X-ray detector comprise an image intensifier
with a corresponding optics or a flat solid-state X-ray detector. This image is further referred
15   to as the first image. In clinical circumstances it may be required to obtain the first image
with a certain orientation. For this purpose the X-ray source 1c together with the X-ray
detector 1d can be rotated about the acquisition volume V about a rotation axis 1e. This
rotation is enabled by a movement of the gantry 1a, which is usually rotatably mounted on a
suitable gantry support means (not shown). The first image is forwarded to the control and
20   processing means 10. The control and processing means 10 comprise an image processing
means 3, which is arranged to compress the first image into the second image. For this
purpose the image processing means 3 can be arranged to address a pre-stored grey-level
compression function 3a, or alternatively the image processing means 3 can be arranged to
interact with a computing means 8. In the latter case the image processing means 3 makes
25   available the first image to the computing means 8 where a corresponding grey-level
histogram is calculated. The grey-level histogram is used to determine the boundaries of the
first linear range, the second linear range and the third linear range for an individualized
grey-level compression. It must be noted that for a majority of cases a usage of a pre-stored
universal grey-level compression function will suffice. Upon a compression of the first image
30   with the grey-level compression function the resulting second image is forwarded to the
control means 6, which is arranged to compute an average pixel grey value of the second
image and to compare it with a pre-stored reference value. In case the computed average
value substantially deviates from the pre-stored reference value a dose control signal C is sent
to the X-ray source 1c in order to modify its settings. Preferably, an intensity of the X-ray

beam is modified. As a result an image with an optimal average pixel grey value is generated. Methods of suitable dose-control are known per se in the art; therefore a generation and an application of the dose control signal will not be explained in further detail.

Preferably, the X-ray examination apparatus further comprises a viewing
5   station, whereto the resulting image with desired pixel grey level is forwarded. The gain of the dose control loop will decrease by the non-linearity of the compression function, resulting in slow control speed. For diagnostic purposes it may be required to restore the linear relation between the grey-level of the resulting image and the X-ray intensity. For this purpose the computing means 8 is arranged to compute a loop gain correction, which can be done
10 according to a following example method:

The mean value of the measuring field in the first image is given by:

$$MEAN = \frac{I * L * f_L + I * M * f_M + I * H * f_H}{f_L + f_M + f_H}$$

15

where,

L, M, H are the average transmission factors of the respectively lower, medium and high part of the compression function

f_L, f_M, f_H are their respective measurement field fractions

20 I is intensity of the X-ray beam.

The mean value of the measurement field after the compression function is applied is given by:

$$MEAN' = \frac{\alpha_L * I * L * f_L + O_L * f_L + I * M * f_M + \alpha_H * I * H * f_H + O_H * f_H}{f_L + f_M + f_H}$$

25

where,

α_L, α_H are respective gradients of the linear lower and linear upper parts of the grey-level compression function;

30 O_L, O_H are respective offsets of the linear lower and upper parts of the grey-level compression function.

The resulting loop gain correction function is given by:

7

$$\text{GainCorrection} = \quad \frac{d(\text{Mean})/dI}{d(\text{Mean'})dI} = \quad \frac{L*f_L + M*f_M + H*f_H}{\alpha_L*L*f_L + M*f_M + \alpha_H * H *f_H}$$

After an application of the loop gain correction to the dose control signal the

5   time behavior of the control loop is restored.

The viewing station comprises a suitable processor 5 and a console 5a
whereon the diagnostic image is displayed by means of a suitable user interface 5c. In case a
user wishes to amend the diagnostic image an input device 5b is provided. After the
diagnostic image has been analyzed, it can be stored in a suitable database 7.

10   Figure 2a presents a schematic view of a first embodiment of resulting
computed average by means of application of a tri-linear grey-level compression function. In
this embodiment a following situation is described: a grey-level compression function CC
comprises three linear intervals, schematically given by I, II, III and is set as a function of a
pixel value PV of a grey value GV. The first linear range I has a substantially lower grey

15   level compression factor than the second linear range II. The first linear range I is selected so
that a weight of low-lighted pixels in the measuring field is substantially reduced. The second
linear interval II is selected to comprise a value of the controlled average CA, which is
referred to as the pre-stored reference value. In this example the measuring field comprises a
main part M, which falls into the second linear range and a highlighted part HL, which falls

20   into the third linear range. By applying the grey-level compression function a presence of the
highlighted part in the measuring field will be compensated, shifting the average value M to
the left with respect to the controlled average CA. An absolute value of the shift is low due to
the reduced grey level compression factor of the third linear interval. If the lower inclination
point is chosen too high, the average value M will partly shift to the first linear interval.

25   Because of the low grey level compression factor of the first linear interval the control
balance will shift the error E much further to the low side to reach a compensation for the
highlight. Therefore, the position of the inclination point must be chosen low enough. A
suitable way to select the boundary of the respective intervals will be discussed with
reference to Figure 3.

30   Figure 2b presents a schematic view of a second embodiment of resulting
computed average by means of application of a tri-linear grey-level compression function. In
this example the region of interest itself comprises a main part M falling into the second
linear interval and a high part falling into the third linear interval. In this case the controlled
average will shift the region of interest to a higher value. The mean error E depends on the

8

level of the upper inclination point and on a grey level compression factor of the third linear
interval III. By properly selecting both parameters the error E is kept low.

    Figure 3 presents a schematic view of an embodiment of a grey-level
histogram of an acquired X-ray image. The grey-level histogram is scored as a number of hits

5 N of pixels with a certain grey level GV versus the absolute value of the grey level GV. From
the grey-level histogram is follows that for a typical first image a number of ranges can be
identified. The lowest range corresponds to a low-lighted areas LL within the measuring
field. This ranged is followed by a main part M of the region of interest. Typically, this range
is centered around a grey level of 500. The main part M of the region of interest is followed

10 by a high part H of the region of interest whereto high-lighted pixels from clinically relevant
areas fall. The highest range corresponds to a high-lighted part of the measuring field HL,
whereto belong high-lighted pixels from beyond the region of interest. From the analysis of
the histogram it follows that it is preferable to select the reference grey-level value at about
500, the respective boundaries of the corresponding linear intervals of the grey-level

15 compression functions being accordingly selected from the histogram. For example, the
boundary between the first and the second linear intervals can be set at 100, the boundary
between the second and the third linear interval can be set at 600. The boundary between the
high part H and the high-lighted part HL is a subjective discrimination between region of
interest or non-region of interest pixels. It must be noted that the way the histogram looks is

20 dependent on the set-up of the X-ray unit and an orientation of the X-ray beam with respect
to the patient. Therefore, it is advantageous to analyze the histogram for each individual set
of images in order to achieve an individualized accurate dose control system.

    Figure 4 presents a schematic view of an embodiment of an implementation of
the method according to the invention. The first image 24 is acquired by means of an X-ray

25 examination unit 22. The first image is forwarded to the image processing means 26 where a
grey-level compression function is applied to the image. Also, the image processing means
26 compute the loop gain correction factor 30. At a following step an average value of the
compressed image is calculated by means of a suitable computing means 28. The average
value is then forwarded to a control means 38 where the average value is compared to a pre-

30 stored reference value. The reference value is addressed by the control means 38 from a look-
up table 36. The control means 38 receives the values of gain 32 and limit 34 in order to
calculate a necessary value of a control signal C to be applied to the X-ray unit 22 by means
of a multiplying means 40. Preferably, the multiplying means receives an additional signal
specifying a calculated loop gain correction factor 30.